THIS PAGE BLANK (USPTO)

The Patent Office

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed

Dated 18 MAR 2000

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
A
13 JUL 1999
RECEIVED BY FAX

The Patent Office

JUL99 E461 D027 /7700 0.00 991 .6

1/77

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent C
Cardiff Road
Newport
Gwent NP9 1

1. **Your reference**
   DC286.P97.028

2. **Patent application number** *(The Patent Office will fill in this part)*
   9916339.6

3. **Full name, address and postcode of the or of each applicant** *(underline all surnames)*
   Coherent Optics Europe Limited
   27-35 Ashville Way
   Whetstone
   Leicestershire
   LE8 6NU
   UK

   Patents ADP number *(if you know it)*
   07139553001

   If the applicant is a corporate body, give the country/state of its incorporation

4. **Title of the invention**
   Induced Absorption Filter

5. **Name of your agent** *(if you have one)*

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*
   Chris J Tillbrook & Co
   1 Mill Street
   Warwick
   CV34 4HB

   Patents ADP number *(if you know it)*
   06097562002-

6. **If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and** *(if you know it)* **the or each application number**

Country	Priority application number *(if you know it)*	Date of filing *(day / month / yea*
n/a		

7. **If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application**

Number of earlier application	Date of filing *(day / month / yea*
n/a	

8. **Is a statement of inventorship and of right to grant of a patent required in support of this request?** *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body.
   See note (d))

   Yes

Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	13
Claim(s)	7
Abstract	1
Drawing(s)	7

10. If you are also filing any of the following, state how many against each item.

Priority documents	0
Translations of priority documents	0
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	1
Request for preliminary examination and search *(Patents Form 9/77)*	0
Request for substantive examination *(Patents Form 10/77)*	0
Any other documents *(please specify)*	0

11. I/We request the grant of a patent on the basis of this applica

Signature Chris J Tillbrook & Co Date 13 July

Chris J Tillbrook & Co 13 July 199

12. Name and daytime telephone number of person to contact in the United Kingdom

Jenny Atkinson
01926 490929

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publica or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. Yo will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getti written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 50050.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

d) *If you have answered 'Yes' Patents Form 7/77 will need to be filed.*

e) *Once you have filled in the form you must remember to sign and date it.*

f) *For details of the fee and ways to pay please contact the Patent Office.*

'Induced Absorption Filter (IAF)'

This invention relates to optical interference filters, their adaptation to tunable filters and their deployment in lasers - in particular, but not exclusively, tunable lasers, or those which 'lase' at several (discrete) wavelengths.

An aspect of the invention is concerned with a selective, narrow-band(width), absorption filter.

Another aspect of the invention is concerned with a monolithic, continuously variable (wavelength) filter.

Yet another aspect of the invention is concerned with a laser deploying the subject filters, bounding an excitation medium.

A still further aspect of the invention is concerned with a tunable, or 'multiple-line', laser - configured to engender dedicated excitation, at a selectable one or more particular wavelengths.

The various aspects are generally applicable to a range of wavelengths, but on occasion particular emphasis is given to certain regions of the spectrum.

Interference Filters

Reverting to interference filters *per se*, an instance is a narrow-band, absorption filter .

This absorbs, (or attenuates) strongly at a discrete wavelength, whilst being non-dissipative (eg highly reflective) in spectral regions both immediately above and below this wavelength.

Many types of interference filter are known.

These include long wave-pass, short wave-pass, band-pass filters, dielectric enhanced metallic reflectors, induced transmission filters and broad-band absorption filters.

A particular instance is a so-called 'thin film' interference filter.

Many of these filter types are described in, for instance, 'Thin-Film Optical Filters', by H A Macleod, (2nd edition, published by Adam Hilger).

Broad-band absorption filter types are described in EP 0921 419 A1 'Revetment absorbeur de lumiere a haut pouvoir absorbant', of inventors Quesnel and Chaton.

Prefacing Statement of Invention

The present invention addresses a new class of thin-film, dielectric, interference filter construction, which effects narrow-band absorption.

Versions of such a filter are useful in 'tuning' laser excitation and radiation, such as in a carbon dioxide (CO_2) lasing medium.

Background Art - Dielectric Filters

A simple (dielectric) band-pass filter consists of two dielectric 'stacks' - acting as (reflector) mirrors - disposed at opposite sides of a dielectric 'spacer' layer.

Resonance is set up, or engendered, (in the spacer layer) between such opposed (dielectric stack) reflectors.

This resonance causes, or allows, transmission of light, at a particular wavelength - in practice equal to half the optical thickness of the spacer layer.

A high level of reflectance (ie non-transmission) is achieved at both sides of a (transmission) pass-band.

Fabry-Perot Filter

One well-known type of (dielectric, interference) filter is the so-called Fabry-Perot filter.

The principles of the Fabry-Perot filter are described, for example, in the references:

'Thin Film Optical Filters', by H.A.Macleod, 2nd edition, published by Adam Hilger, pp238 to 257;

and

The Optical Society of America's 'Handbook of Optics', published by McGraw Hill, pp8-76 to 8-80.

Fabry-Perot filters are based upon an interferometer of the same name, employing two identical reflecting surfaces, spaced apart by a set distance.

A Fabry-Perot filter contains the same essential components - namely two reflectors and a spacer.

The reflectors can either be metallic layers, or dielectric stacks.

Essentially, such a dielectric (reflector) stack is a (sequential) multi-layer, or tiered, structure - of alternating layers of differing refractive indices.

This stack acts like a (partially) reflective mirror, but has essentially no absorbing component.

Thus, constructionally, it is important that the intervening spacer layer is a non-absorbing material.

Generally, a Fabry-Perot filter has three basic components, positioned in a particular relative disposition, or sequence, as follows:

- a 'partially-reflective' mirror,
- a non-absorbing, dielectric 'spacer' layer, and,
- a second, 'partially-reflective', mirror.

Light is typically incident upon a first mirror in this sequence.

Both partially-reflective mirrors typically have a

near-unity reflectance factor (for certain reflected wavelengths).

In the particular case of a 'thin-film' Fabry-Perot filter, the two mirrors each commonly comprise (sequentially-stacked) tiered dielectric layers - of alternating (relatively) low and high refractive indices.

Here, again the reflectance factor of each thin-film mirror stack is close to unity, *for certain wavelengths.*

A Fabry-Perot filter has a resonance at a wavelength equal to one half of the optical thickness of the spacer layer.

Thus the thickness of the spacer layer is typically a 'half-wave' optical thickness.

In a thin-film Fabry-Perot filter, with all-dielectric layers, a very narrow wavelength band - centered at the resonant wavelength - is transmitted through the filter.

Incident light, at broad wavelength regions, on both sides of this narrow wavelength band, is highly reflected (again, a near-unity reflectance factor).

Although not generally accepted thin-film filter terminology, a thin-film, Fabry-Perot filter could be categorised as an Induced Transmission Filter (ITF).

Statement of Invention

Induced Absorption Filter (IAF)

In certain respects, an Induced Absorption Filter (IAF), according to one aspect of the present invention, represents both a development of - and significant departure from - a Fabry-Perot filter, or ITF.

More specifically, in an IAF according to the invention, a second dielectric mirror stack of the ITF configuration is replaced by a high reflective, opaque, metal layer.

The opacity of this second mirror suppresses light transmission *at certain wavelengths* - thus representing a significant distinction from, and differentiation over, an ITF.

Retention of a spacer layer, preserves a three component configuration of a

Fabry-Perot Filter, or ITF - and therefore its resonance.

However, a significant distinction over an ITF arises, since:

- a narrow wavelength band, centered at the resonant wavelength, is essentially not reflected (near-zero reflectance factor), and
- the second mirror is opaque.

Thus, this narrow wavelength band is highly absorbed (by a factor of near-unity), in an IAF according to the invention.

Essentially, a filter according to the invention induces narrow-band absorption - hence the designation Induced Absorption Filter (IAF) - whilst highly reflecting (broad) wavelength bands, both above and below the absorbed wavelength band.

IAF General Case Embodiments

Generally, a thin-film IAF, according to the invention, is typically deposited upon a substrate, as the following layer sequence:

- a metal mirror (opaque metallic thin film),
- a dielectric 'spacer' layer, and
- a dielectric mirror stack.

Light is incident upon the dielectric mirror stack.

Alternatively, a highly reflective metal substrate could replace the metal mirror.

The resonant wavelength of the IAF is typically the laser wavelength to be suppressed.

In some cases, there may be a plurality of laser wavelengths to be suppressed.

An IAF according to the invention can accomplish this, based upon the following general rules:

Rule 1

If the dielectric spacer layer is, or comprises, a low refractive index material;

where the dielectric mirror stack comprises:

- the same (or similar) low refractive index material; and
- a (relatively) high refractive index material;

the primary resonant wavelength occurs when the spacer layer is equal to even

integer multiples of quarter-waves (optical thickness), including zero (absentee layer).

The corresponding primary resonant wavelength equals the optical thickness of the quarter-wave - independently of the multiple of the selected quarter-wave thickness.

The overall stacking configuration can be described symbolically, as:

Substrate / T nL (HL)^x H /ambient

... where:

T is a metal mirror thin film;

'n' = 0,2,4,6, etc... is an <u>even</u> integer multiple of the quarter wave optical thickness of the spacer layer;

H and L represent quarter wave optical thicknesses, respectively of high and low refractive index layers; and
'x' is a number of pairs of H and L layers required to produce a high reflectance mirror.

<u>Rule 2</u>

If the dielectric spacer layer is, or comprises, a <u>high</u> refractive index material;

where the dielectric mirror stack comprises:

- the <u>same</u> (or similar) <u>high</u> refractive index material; and
- a low refractive index material;

the primary resonant wavelength occurs when the spacer layer is equal to <u>odd</u> integer multiples of quarter-waves (optical thickness), including zero.

The corresponding primary resonant wavelength equals the optical thickness of the quarter-wave - independently of the multiple of the selected quarter-wave optical thickness.

The overall stacking configuration can be described symbolically, as:

Substrate / M nH (LH)^x /ambient

n = 1,3,5,7,...

Rule 3

For both cases of the spacer layer, ie whether of either high or low refractive index:

as the integer multiple of the quarter wave optical thickness is increased,

the secondary resonant wavelengths move closer to the primary resonant wavelength.

The secondary resonant wavelengths are present, regardless of the integer multiple - and also occur for real number multiples in-between the prescribed integer multiples.

The required spacer layer thickness for the desired spacing of the resonant wavelengths can be directly calculated, based upon formulae for Fabry-Perot filters from standard thin-film texts.

Illustrated Example of Fabry-Perot Filter

A typical (all) dielectric Fabry-Perot filter construction is depicted in Figure 1 of the drawings.

A transparent spacer layer 14 is enclosed between two reflecting dielectric stacks 11, 13 - each a multi-layered tier of alternating refractive index materials.

Incident light radiation 12 is transmitted through this configuration 10 - at wavelengths proportional to the thickness of the spacer layer 14 .

Typical overall filter performance is represented graphically in Figure 2.

Filter aspects of the present invention are concerned with variants of such a stacked array of multiple dielectric layers in juxtaposition.

Statement of Invention

According to one aspect of the invention,
a filter comprises, (in part)
a dielectric stack reflector,
in (intimate) juxtaposition with,
a metal (such as gold) layer,
with a high absorption coefficient,
and high reflectivity,
and an intervening spacer layer.

A particular wavelength operating band is in the region from 9 through to 14 μm.

An alternative band would be from 8 to 12 μm.

The invention also provides an optical element, comprising a substrate, with a metallic spacer coating upon the substrate surface, the coating being of (high) average (say, >99%) reflectivity, over an operating wavelength band, in the range of some 8

through to some 12 µm, whilst substantially absorbing radiation in a relatively narrow wavelength band, (typically, some 250 nm), within said wavelength band.

In some configurations, the substrate itself is metal, or metallic, and the metal or metallic spacer coating serves for absorption induction.

In other configurations, the coating serves for <u>both</u> reflection and absorption - whatever the substrate.

Such a configuration represents an essentially new type of (thin film) interference filter - and one for which the term 'Induced Absorption Filter' (IAF) has been coined.

In characterising, or differentiating, Induced Absorption Filter construction according to the invention, over the known filter art, the '<u>transparent</u>' dielectric spacer layer of a conventional filter stack, such as of the Fabry-Perot configuration, is replaced by an <u>absorbent</u> material.

<u>Illustrated Example of Induced Absorption Filter (IAF)</u>

More specifically, referring to Figure 3 of the drawings, a dielectric stack 19, of alternating layers 16, 18 of different refractive index H, L, is disposed upon an absorbent (as opposed to transparent in an ITF), dielectric 'spacer' layer 20.

The spacer layer 20 is in turn disposed upon a metal layer 21, such as gold, with a high <u>reflectivity</u>, for certain wavelengths of incident light.

The metal layer 21 could be a coating upon a substrate (not shown), or alternatively could be substituted by a metallic substrate (not shown).

The roles of the spacer layer 20 and metal layer 21 could be consolidated.
Thus, the metal layer 21 could itself serve as a spacer layer (or vice-versa), given a high <u>absorption</u> coefficient, for certain wavelengths, in addition to a high reflectivity for certain other wavelengths.

In that respect, the metallic layer 21 would have a dual role.

The incident light wavelength or band, upon the spacer layer 20, and/or the metallic layer 21, reflects in part the refractive indices of layers 16, 18 in an overlying dielectric stack 19.

Moreover, since the metal/spacer layer 20 is effectively 'opaque', a 'rearward' (ie in relation to incident optical beam 'viewing' direction) dielectric stack cannot be 'seen' or 'perceived' - so serves no purpose, and can be omitted.

The significance of the multi-layer, tiered, dielectric stack 19 configuration, of successive, alternating, material layers 16, 18 of differing - ie relatively high (H) and low (L) - refractive index, is discussed later in Examples 1 through 3.

Generally, certain wavelengths of incident light radiation 12 pass through the dielectric stack 19 and 'see' or 'perceive' a 'virtual image' of the (dielectric) stack 19.

reflected in the metal 20.

Thus, the overall filter structure 'appears' - to incident light 12 - to be a band-pass filter, as depicted graphically in Figure 5.

A particular incident radiation wavelength 12 - in practice a function of dielectric stack 19 layer thicknesses - tries to pass through the spacer layer 20, but is strongly absorbed,

This is due to the high extinction (or absorption) coefficient of the spacer layer 20, *at that wavelength*.

The remaining wavelengths of incident light 12 are efficiently reflected, due to a combination of the dielectric stack 19 and the spacer layer 20 - which, *at other wavelengths*, act as a reflectance enhancer.

In that respect, a metal/spacer layer 21/20 can have a dual absorbent spacer and reflector role.

The metal spacer layer 21 need not be configured as a discrete deposition or coating upon a substrate.

Rather, a dielectric stack 19 (and dielectric spacer layer 20) could be applied directly to a suitable metal substrate (not shown) - which, when used in high power applications, could be actively cooled.

The overall Induced Absorption Filter (IAF) construction, according to one aspect of the invention, is straightforward - and in physical thickness amounts to less than half that of an equivalent Fabry-Perot band-pass filter.

Such an Induced Absorption Filter (IAF) can be fabricated by a selective, or variable, coating technology (described later), in order to achieve a tunable filter performance.

Firstly though, the application of Induced Absorption Filter technology to a laser, according to another aspect of the invention, will be described.

Laser Application of Induced Absorption Filter (IAF)

In some circumstances, the ability of lasers, such as a carbon dioxide (CO_2) medium laser, to operate at more than one wavelength - with an overall performance as depicted graphically in Figure 4 - can be detrimental.

Thus, in most applications, such as cutting, welding, etching and marking, it is desirable for the properties of the beam to remain constant throughout the operation.

It is not therefore beneficial if the laser 'drifts' - that is skips from one operating wavelength to another, or if it operates at several wavelengths simultaneously.

Most lasers consist of a tube of lasing medium (such as CO_2), contained between two (reflecting) mirrors.

Radiation travelling backwards and forwards between the two mirrors results in light amplification, by stimulated emission of radiation.

Supplementary Statement of Invention - Laser

According to another aspect of the invention
a laser resonator
is terminated by first and second mirrors,
bounding an intervening lasing medium,
which, upon being energised,
can provide gain,
at first and second wavelengths,
at least one of the mirrors
having sufficient reflectivity at the first wavelength that laser radiation is generated by the resonator, upon excitation of the gain medium,
whilst being sufficiently absorptive,
at the second wavelength,
that laser radiation is not generated by the resonator, on the same excitation.

The laser will only operate at wavelengths at which the mirrors are highly reflecting (ie reflectively efficient).

If it is desired to constrain the operating wavelength to, for instance 10.6 μm, it is possible, according to another aspect of the invention, to replace the mirrors with Induced Absorption Filters according to one aspect of the invention.

The Induced Absorption Filters prevent, inhibit, or suppress amplification of radiation at either side of a target wavelength.

Thus, in this instance, a filter 26 would be designed to absorb at, for instance, 10.5 μm, at one end of a laser tube 37, and a companion filter 28 at 10.7 μm, at the other - as depicted in Figure 7.

External excitation 36, applied to a lasing medium, in this instance CO_2 gas 38, confined within the tube, promotes a stimulated emission of radiation, or lasing, resonance.

Such radiation is allowed to exit at one end of the confinement tube 37, through a window 34 in the filter mirror 26

Alternatively, if it is desired to use only one mirror, in order to constrain operation of the laser to one wavelength, an induced absorption 'comb' filter could be used - with an overall performance characteristic as depicted graphically in Figure 8.

Laser Tuning - for Cutting/Machining or Welding

Carbon dioxide (CO_2) lasers are often used to cut, machine or weld common fabrication materials, such as metals, wood and plastics.

Many materials, including most plastics, have a series of discrete absorption bands in the Infrared.

By adoption of IAF technology of the present invention, a laser could be 'tuned' to operate at a wavelength corresponding to that of an absorption band of the material being cut.

Thus, rather than much of the energy being transmitted through the plastic, it would all be absorbed and so contribute to an energy transfer to the material.

The (cutting, machining or welding) operation would then become much more efficient.

Thus a tuned laser would be able to cut or melt the material much more quickly.

Alternatively, a smaller, less expensive, laser than that of a conventional laser employed hitherto, could be used for the task.

A simple IAF filter device could be used actively to tune carbon dioxide lasers.

Laser Marking

Lasers are often used to apply identification marks, or decorative pattern, for materials such as plastics woods, or metals.

Improved edge definition - and therefore, a sharper image - is obtained with monochromatic laser radiation, achievable with an IAF tuned laser according to the present Invention.

3D Filter Coating

The Applicants have developed a thin film, three-dimensional (3D) variable coating technology - the subject of their pending UK Patent Application 9722295.4, and corresponding US Patent Application 08/891,750.

This enables controlled (coating) thickness, or depth, grading of optical thin films, in relation to spatial position, upon a substrate.

In an Induced Absorption Filter according to one aspect of the invention, the wavelength at which radiation is absorbed is dependent only upon the thickness of the dielectric layers.

Taken in conjunction with the Applicants' aforementioned variable coating thickness technique, a variable absorption wavelength filter is achievable.

Supplementary Statement of Invention
- Variable Filter

According to yet another aspect of the invention, (dielectric) layers are graded (or progressively varied) say, circularly and/or linearly, in thickness, over the surface of a filter, whereby, at different positions on the surface, a different wavelength is absorbed.

Thus, by rotating, and/or translating, [juxtaposed] circular or linear variable (wavelength) induced absorbing filters (relatively to one another and/or an incident light), they become 'tunable'.

With a filter position/orientation control mechanism, such variable coating filters could be operated co-operatively in tandem, in order to enforce light amplification at any wavelength at which a laser is capable of operating.

Known Diffraction Grating Tunable Filter Art

In effect, the filters form an (relatively inexpensive) alternative to the diffraction grating (and associated mechanisms), commonly used to perform a tuning function, as exemplified by, say, the references:

- 'An independently controllable multi-line laser resonator and its use in multi-frequency injection locking', by R.L.Sheffield, S.Nazemi and A.Javan, Advanced Physics Letters 29, pp 588 to 590; and
- 'A compact, simple stepping motor controlled laser grating mount', by T.W.Carmen, P.E.Dyer and P.Monk, J. Phys E. 13).

Whilst carbon dioxide lasers have been referred to in the illustrative example above, the tunable filter technique according to the invention could be applied to other areas of the (optical) spectrum, such as the visible, near, or medium wave infrared.

Specific Embodiments

There now follows a description of some particular embodiments of the invention, by way of example only, with reference, on occasion, to the accompanying diagrammatic and schematic drawings.

A dielectric stack filter coating utilises sequentially-tiered, paired layers 16, 18 of (relatively) high H (or medium M) and low L refractive index material, in relation to an intended operating wavelength.

Such 'index-pairs' (H/M-L) could consist of zinc sulphide or selenide, in combination with either thorium fluoride, or germanium.

The layers are deposited alternately.

Their respective quarter-wave optical thicknesses are close to (but not exactly) the wavelength at which absorption is required.

In the examples below, the material pair used is:

- zinc sulphide - of quarter-wave optical thickness 'M'; and
- thorium fluoride - of quarter-wave optical thickness 'L'.

As with band-pass filters, there is an almost unlimited variety of constructions that could be used.

The design examples shown below are relatively straightforward, and use gold (Au) as a metal (absorption) layer, whose thickness is not critical.

Example 1:

Au (M L)^4 M / air

... where M and L equal one quarter-wave optical thicknesses, of relatively medium and low refractive index materials, respectively.

Example 2:

Au MM (M L)^4 M / air

... where M and L equal one quarter-wave optical thicknesses, of relatively medium and low refractive index materials, respectively.

Calculated spectral performances of Examples 1 and 2 are depicted in Figure 5.

Actual performance of Example 1 is shown in Figure 6.

Those skilled in the art will recognise that additional dielectric spacers (not shown) could be incorporated, in order to steepen the absorption edge (or sharpen the transition between absorption and reflection) - and so 'square off' the performance of the filters.

With an Induced Absorption Filter (IAF) configuration according to the invention, the effect of additional dielectric spacers is doubled - since the incident radiation also 'sees' a virtual spacer (not shown).

Yet another aspect of the invention provides an Induced Absorption Comb Filter, of configuration:

Example 3:

$$Au\ (M\ L)^2\ xM\ (L\ M)^2$$

... where M and L equal one quarter-wave optical thickness, of relatively medium and low refractive index materials, respectively.

and x = lies generally in the range of about 4 through 1000; for example x = 100.

The performance of this filter (where x =100) is depicted in Figure 8.

Component List

10	filter configuration
11	dielectric stack (Fabry-Perot filter)
12	incident light
13	dielectric stack (Fabry-Perot filter)
14	dielectric spacer (Fabry-Perot filter)
16	high (H) refractive index material
17	substrate
18	low (L) refractive index material
19	dielectric stack (IAF)
20	dielectric (absorbent) spacer layer (IAF)
21	metal layer (IAF)
26	filter mirror
28	filter mirror
34	window
36	excitation
37	laser confinement tube
38	lasing medium (eg CO_2 gas)
39	LASER beam

Claims

1.

An (optical) filter comprising, a reflecting dielectric stack, tiered successively with, a dielectric spacer layer, of high absorption coefficient, and/or a metallic (such as gold) layer, or substrate, of high reflectivity.

2. {absorptive & reflective metallic layer/substrate}

A filter, as claimed in Claim 1, wherein the dielectric stack is deposited upon a metallic layer, or substrate, of high absorption coefficient and high reflectivity.

3. {spatially-variable depth}

A filter, as claimed in Claim 1 or 2, wherein the dielectric stack varies in thickness spatially, over the metallic layer or substrate.

4. {circular variability}

A filter, as claimed in any of the preceding claims, wherein the dielectric stack thickness varies circularly over the metallic layer or substrate.

5. {linear variability}

A filter, as claimed in any of the preceding claims, wherein the dielectric stack thickness varies linearly over the metallic layer or substrate.

6. {tunability}

A monolithic, selectively variable, or tunable-wavelength, narrow-band, absorption filter, comprising a dielectric stack, of spatially varying-thickness, deposited upon an absorbent and reflective metallic spacer layer, or substrate, the wavelength absorbed varying with (linear and/or rotational) position of the stack, in relation to incident light.

7. {stacking sequence - Rule 1}

A single, or multiple wavelength (tunable), optical filter, including a metallic layer, separated, by a dielectric spacer layer, of a low refractive index material, from a dielectric mirror stack, comprising alternating layers, respectively of the same (or similar) low refractive index material, and a relatively high refractive index material; a primary resonant wavelength occurring when the spacer layer is equal to even integer multiples of a quarter-wave (optical thickness), including zero (absentee layer), and symbolically described as;

Substrate / T nL $(HL)^x$ H /ambient

... where:

T is the metal mirror thin film;

n = 0,2,4,6, etc... ; even integer multiples of the quarter wave optical thickness of the spacer layer

H and L represent quarter wave optical thicknesses respectively of the high and low refractive index layers;

8. {stacking sequence - Rule 2}

A single, or multiple wavelength (tunable) optical filter, including a metallic layer, separated by a dielectric spacer layer, of a <u>high</u> refractive index material, from a dielectric mirror stack, comprising alternating layers, respectively of the same (or similar) <u>high</u> refractive index material; and a relatively low refractive index material; a primary resonant wavelength occurring when the spacer layer is equal to odd integer multiples of quarter-wave (optical thickness), symbolically described as;

Substrate / T nH $(LH)^x$ / ambient

... where:

T is the metal mirror thin film;

n = 1,3,5,7,..., odd integer multiples of the quarter wave optical thickness of the spacer layer; and

H and L represent quarter wave optical thicknesses respectively of the high and low refractive index layers;

9. {stacking sequence - Rule 3}

A single, or multiple wavelength (tunable) optical filter, including a metallic layer, separated, by a dielectric spacer layer, of <u>either</u> high <u>or</u> low refractive index material, from a dielectric mirror stack, comprising alternating layers, respectively of relatively high and low refractive index material; the spacer layer thickness being integer multiples of quarter-waves (optical thickness), and, as this multiple increases, secondary resonant wavelengths move closer to the primary resonant wavelength.

10. {stacking sequence}

A single, or multiple wavelength (tunable) optical filter, with a dielectric reflector comprising a tiered multi-layer stacking sequence of:

Au $(ML)^4$ M / air

... where M and L equal one quarter-wave optical thicknesses, of relatively medium and low refractive index materials, such as, respectively, zinc sulphide and thorium flouride.

11. {alternative stacking sequence}

A single, or multiple (tunable) wavelength optical filter, with a dielectric reflector comprising a tiered multi-layer stacking sequence of:

Au MM $(M\ L)^4$ M / air

... where M and L equal one quarter-wave optical thicknesses, of relatively medium and low refractive index materials, such as, respectively, zinc sulphide and thorium flouride.

12. {further stacking sequence}

A single, or multiple (tunable) wavelength optical filter, with a dielectric reflector comprising a tiered multi-layer stacking sequence of:

Au $(M\ L)^2$ xM $(L\ M)^2$

... where M and L equal one quarter-wave optical thicknesses, of relatively medium and low refractive index materials, such as, respectively, zinc sulphide and thorium flouride;

'x' is between about 4 through 1000;
for example x = 100.

13. {squared-off performance}

A filter, as claimed in any of the preceding claims, incorporating additional dielectric spacers, configured to steepen the absorption characteristic edge and so 'square off' filter performance; with a doubling of the effect of additional dielectric spacers, by creating a perception of additional 'virtual spacers', to incident radiation.

14.

An induced absorption filter, configured to operate in the wavelength band 8 to 12μm.

15.

A tunable absorption filter, with a spatially varying reflector coating depth, upon an absorbent layer or substrate, and configured to operate in the wavelength band 8 to 12μm.

16.

A tunable filter, substantially as hereinbefore described, with reference to, and as shown in, the accompanying drawings.

17.

A laser, incorporating an Induced Absorption Filter (IAF), at one end of a resonator.

18.

A laser, incorporating an Induced Absorption Filter (IAF), at each end of a resonator.

19.

A laser, substantially as hereinbefore described, with reference to, and as shown in, the accompanying drawings.

20.

A tunable or multi-line laser, incorporating an Induced Absorption Filter (IAF), at one end of a resonator, and configured to operate in the waveband 8 to 12 μm.

21.

A tunable or multi-line laser, incorporating an Induced Absorption Filter (IAF), at each end of a resonator, bounding a lasing medium, and configured to operate in the waveband 8 to 12 μm.

22.

A tunable, or multi-line, laser incorporating a fixed, or variable, wavelength Induced Absorption Filter (IAF), as claimed in any of the preceding claims.

23.

A tunable, or multi-line, laser substantially as hereinbefore described, with reference to, and as shown in, the accompanying drawings.

24. {laser resonator}

A laser resonator,
terminated by first and second mirrors,
bounding an intervening lasing medium,
which, upon being energised,
can provide (optical) gain,
at first and second wavelengths;
at least one of the mirrors
having sufficient reflectivity, at the first wavelength, such that laser radiation is generated,
by the resonator,
upon excitation of the gain medium,
whilst being sufficiently absorptive,
at the second wavelength,
that laser radiation is not generated
by the resonator,
upon the same excitation.

Abstract

An optical filter uses a multi-layer, tiered stack of alternating dielectric layers (16, 18) of different refractive indices, a dielectric spacer layer (20) and metal layer (21), to achieve a narrow overall absorption bandwidth, with high reflectance upon either side.

A tunable (optical) filter variant uses a dielectric stack coating of spatially-varying thickness, that is a coating of depth varying, say linearly and/or circularly, according to position across an absorbent layer or substrate, whereby, at different positions on the surface, a different wavelength is absorbed.

A tunable laser (35) uses opposed tunable filters (26, 28) bounding a lasing medium (38), such as CO_2 gas, for selective variable stimulated emission of radiation (39).

Figure 3

IAF

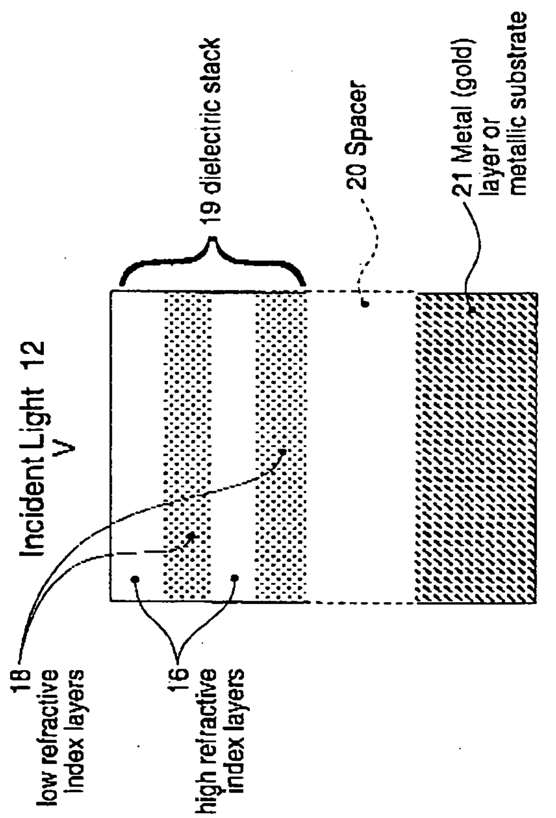

Figure 3

Fabry-Perot Filter

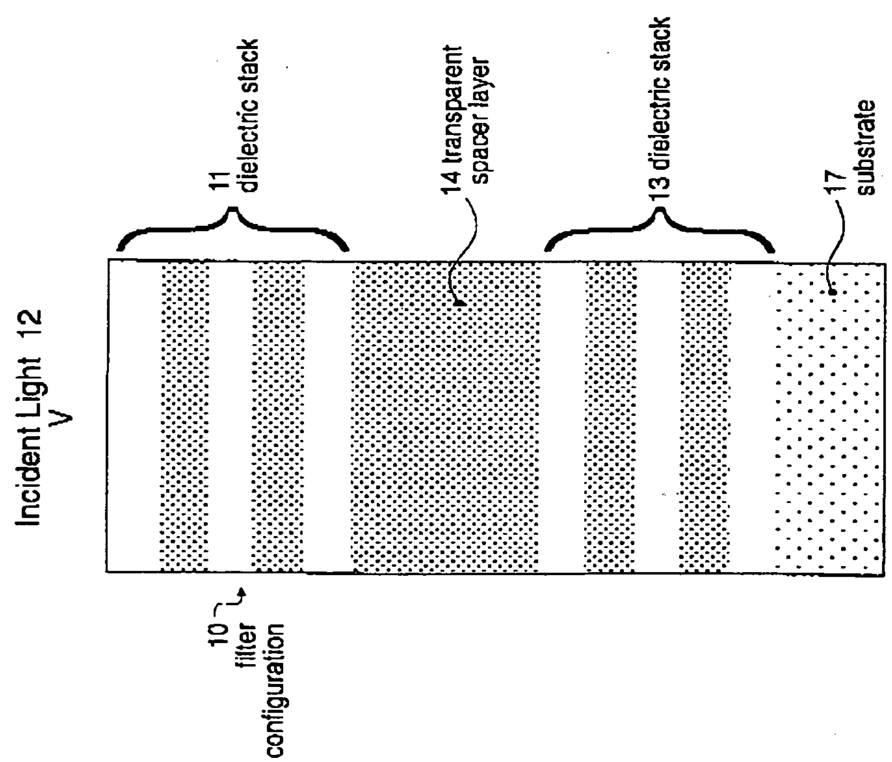

Figure 1

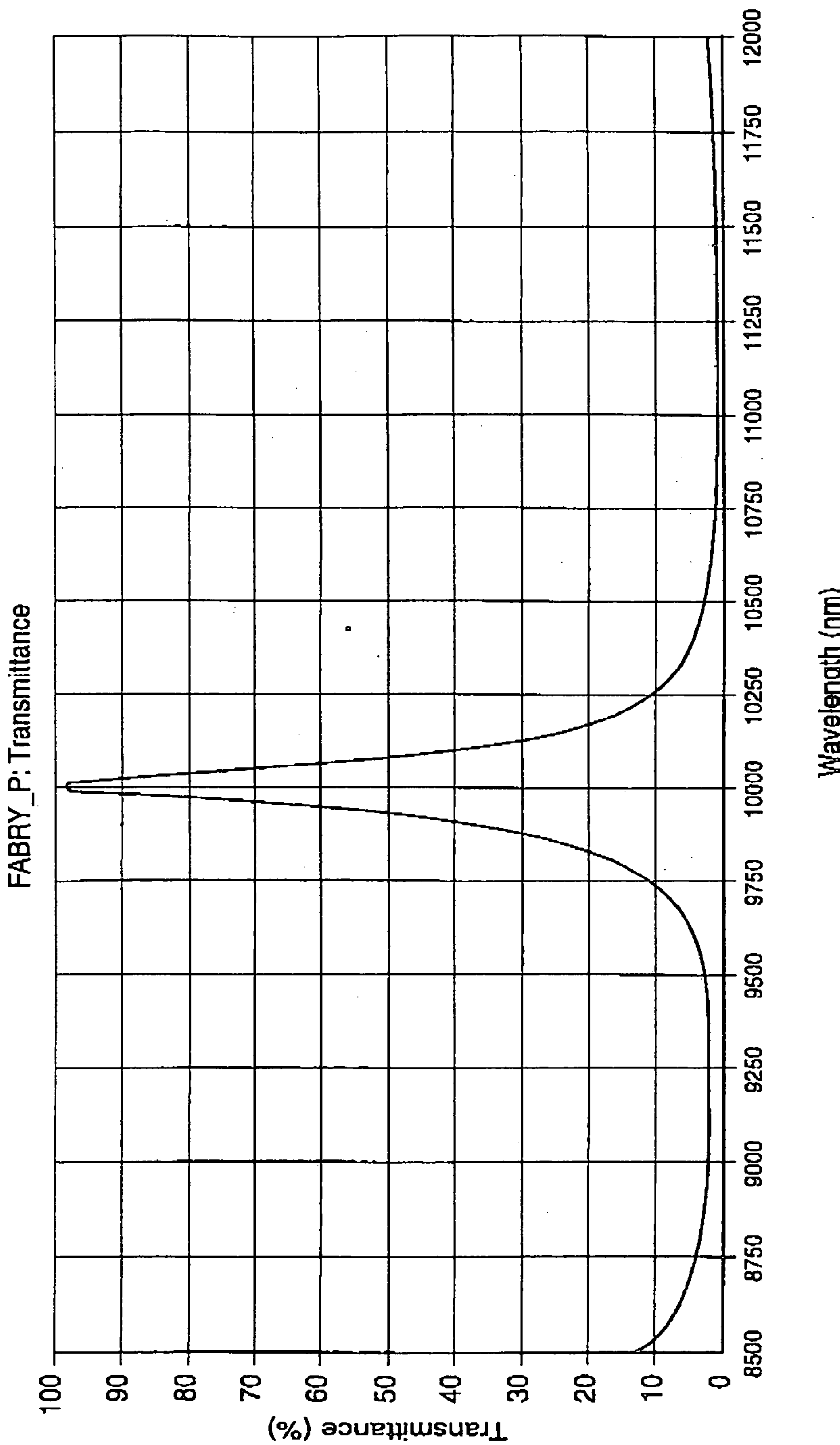
FABRY_P: Transmittance
Transmittance (%)
100
90
80
70
60
50
40
30
20
10
0
8500
8750
9000
9250
9500
9750
10000
10250
10500
10750
11000
11250
11500
11750
12000
Wavelength (nm)

Figure 2

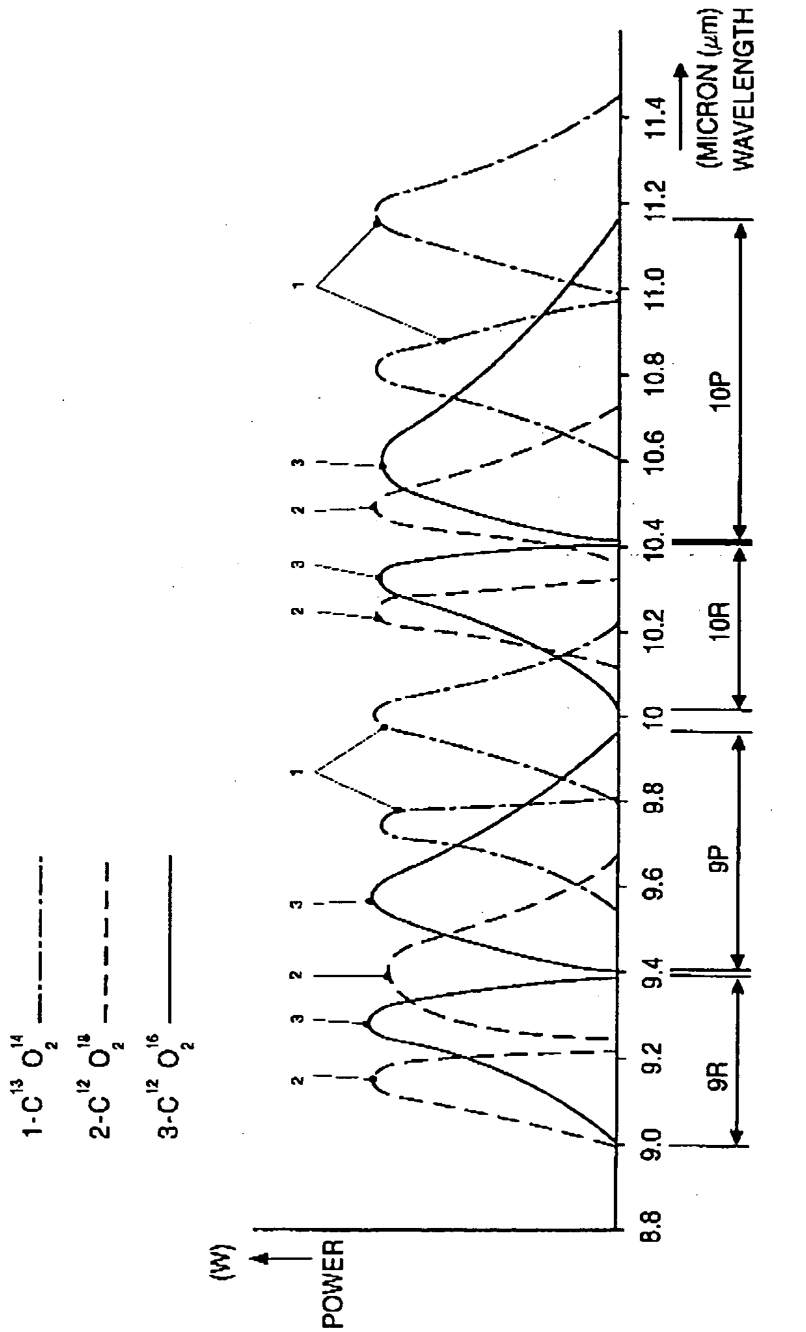
POWER
(W)
WAVELENGTH
(MICRON (μm)
8.8
9.0
9.2
9.4
9.6
9.8
10
10.2
10.4
10.6
10.8
11.0
11.2
11.4
9R
9P
10R
10P

Figure 4

THIS PAGE BLANK (USPTO)

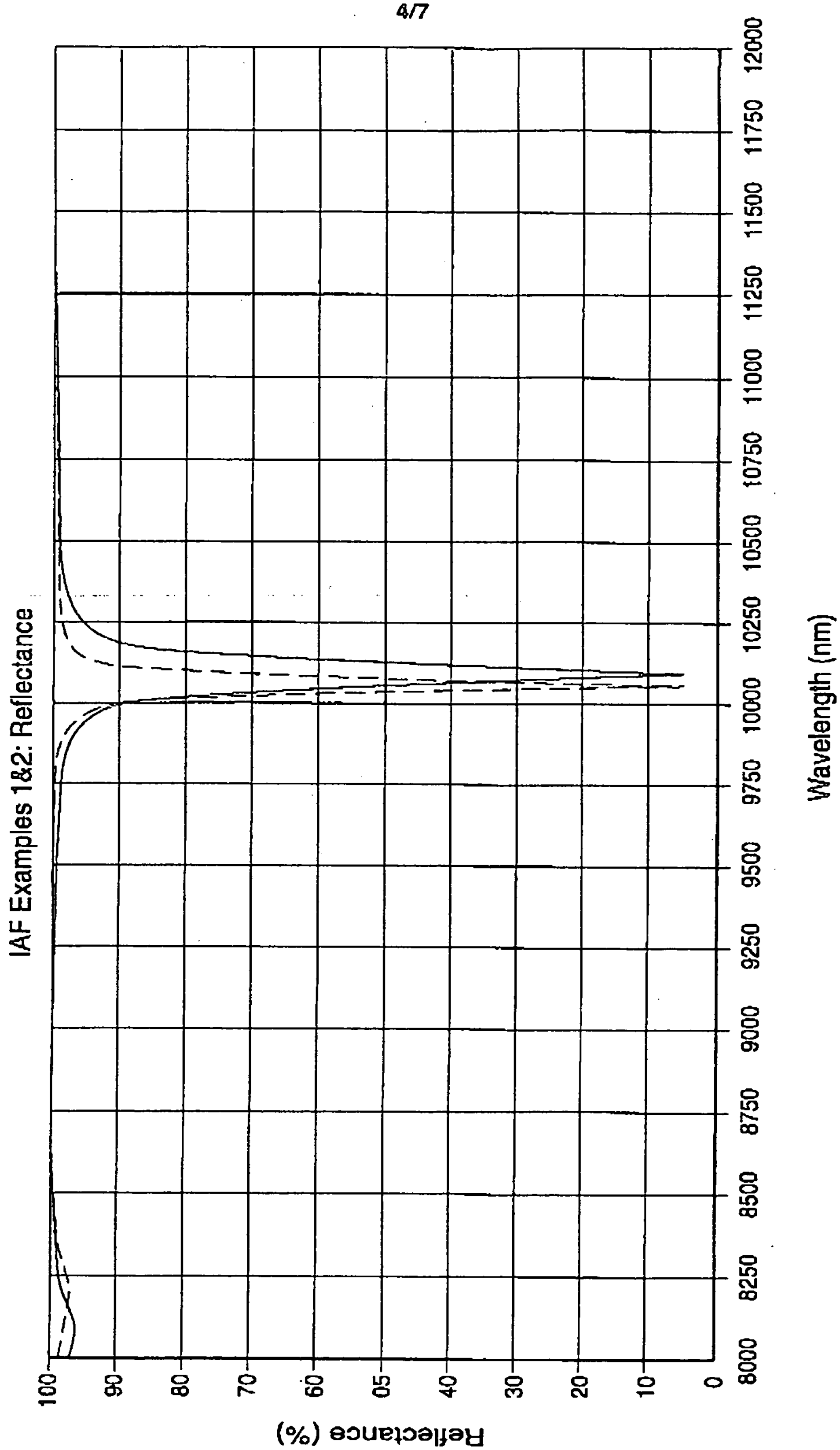
IAF Examples 1&2: Reflectance
Wavelength (nm)
Reflectance (%)
8000 8250 8500 8750 9000 9250 9500 9750 10000 10250 10500 10750 11000 11250 11500 11750 12000
100 90 80 70 60 50 40 30 20 10 0

Figure 5

Performance of Actual IAF : Example 1

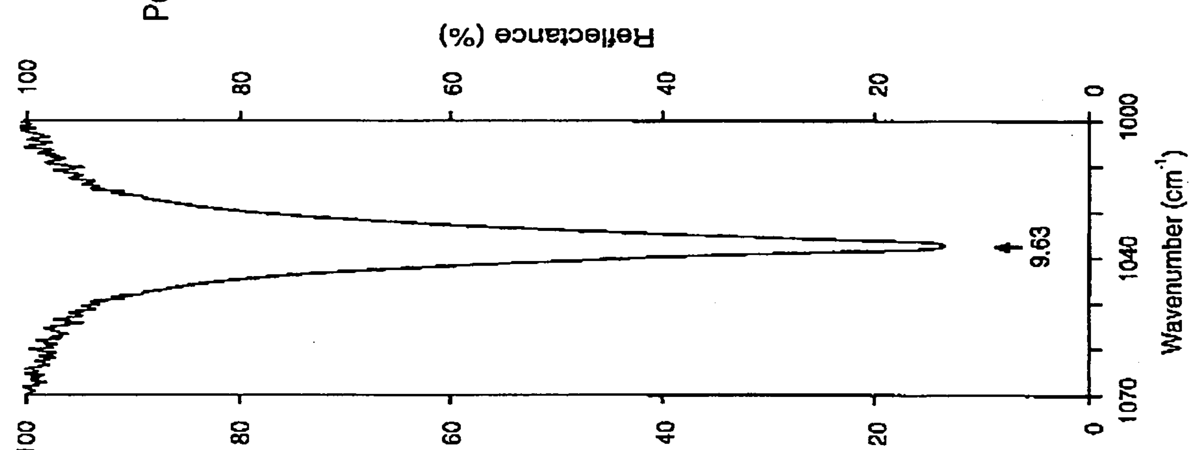

Figure 6

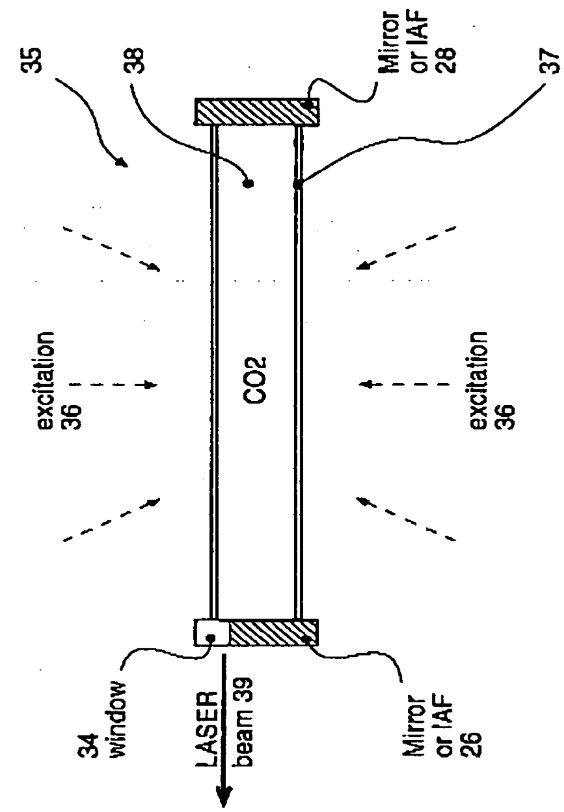
35
38
Mirror or IAF 28
37
excitation 36
CO2
excitation 36
34 window
LASER beam 39
Mirror or IAF 26

Figure 7

THIS PAGE BLANK (USPTO)

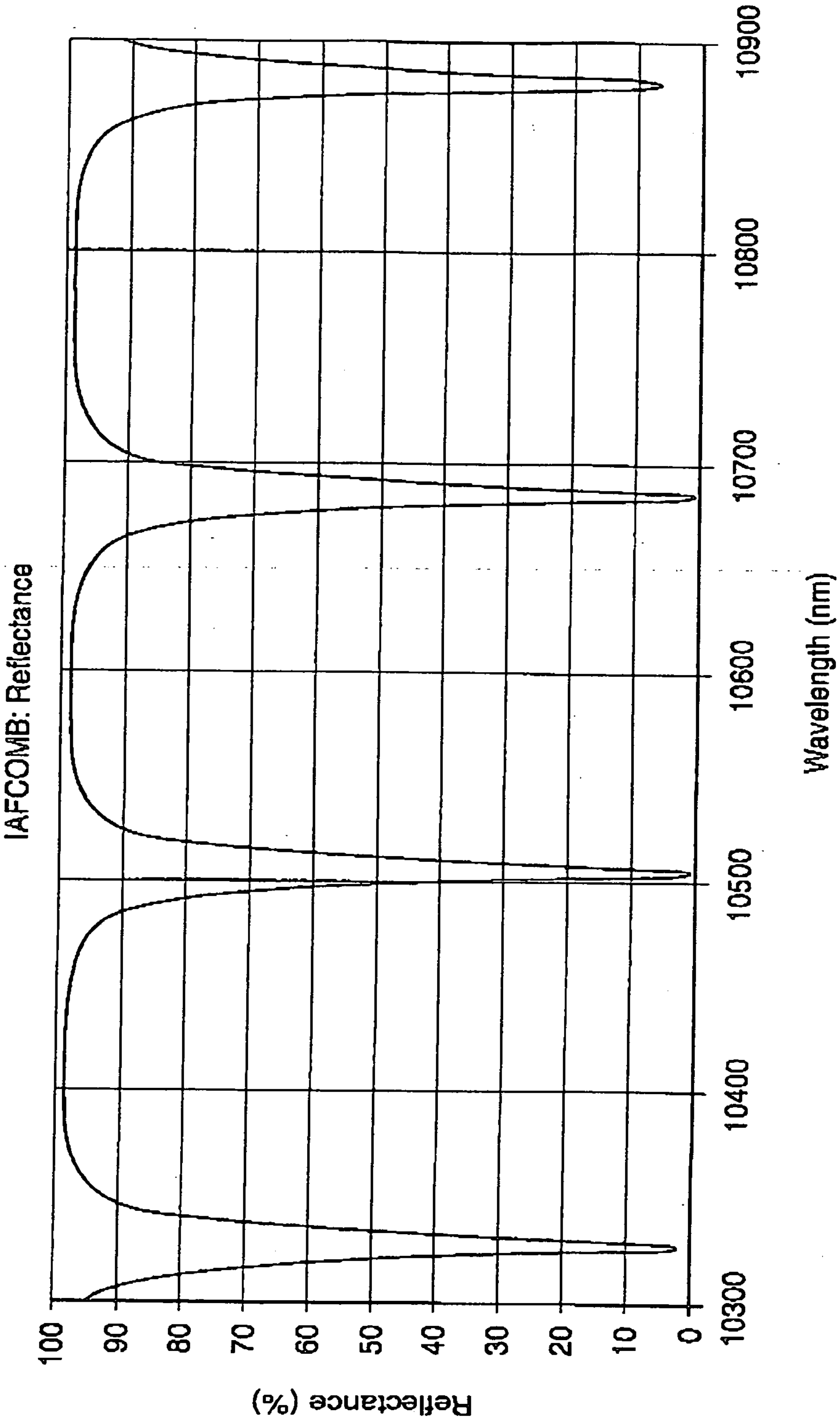
IAFCOMB: Reflectance
Reflectance (%)
100
90
80
70
60
50
40
30
20
10
0
10300
10400
10500
10600
10700
10800
10900
Wavelength (nm)

Figure 8